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Key Technologies of Wireless Sensor Networks: A Review

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Abstract. Wireless sensor network is an emerging technology developing rapidly in the last ten years. Two key technologies of WSN, location-awareness and data fusion are mainly reviewed in this paper. Firstly, the main methods, technical difficulties and future trends of location aware technology are introduced in detail. In addition, the data fusion level and its main algorithms along with advantages and disadvantages are expounded, and the future development of the data fusion technology is prospected.

1. Introduction

Wireless sensor network is a modern information technology which integrates sensors, wireless communication, low-power embedded components and distributed data processing. WSN's network, which is able to implement real-time perceiving, monitoring as well as gleaning data of the specified target in certain regions, is composed of a large quantity of static or dynamic sensor nodes. WSN relies on embedded technology to fuse the acquired data. Finally, wireless communication technology is employed to transmit data to the terminal [1-2].

For the reason of its characteristics concerning self-organization, data dynamics, anti-interference and anti-damage, it owns an extensive range of applications in various fields including military, agriculture, aviation, medical, etc. During the process of researching WSN, location awareness, networking, data fusion and energy management are all crucial techniques requiring massive exploration. In this paper, we concentrate on two of these key technologies, location-awareness and data fusion, and analyze the historical as well as current research status, technical difficulties, and future developing tendency.

2. Location awareness of WSN

2.1. Principles

Location awareness could provide positioning functions similar to global positioning system (GPS), while the former is able to work indoor. For multi-agent wireless networks, location awareness is an indispensable technology which guarantees significance of the observed data by enabling agents to obtain accurate observation messages. In this way, agents' interactions with external environment or adjacent nodes are actualized [3-6].

Location aware algorithms are divided into range-free localization algorithms and range-based ones, and the former includes DV-HOP algorithm, centroid algorithm and ATIP algorithm [3]. The DV-HOP algorithm requires hop distance between target node and anchor nodes as well as the distance per hop to calculate overall distance. Then distances from at least three anchor nodes are required in order to achieve tri-edge measurement or multi-edge measurement utilized as a way of positioning. This



algorithm is capable of avoiding errors from additional hardwares and is relatively unexacting to implement because it does not need direct ranging. The centroid algorithm selects several anchor nodes within the communication range of the target node as particles, and the centroid of polygon constituted by them is utilized as the target's position. This algorithm is reputed as the most classic range-free localization approach. The ATIP algorithm takes advantage of anchor nodes' locations within the target communication range to compose various triangles in the location area. The range of positioning is determined by the spaces overlapping mostly by these triangles, and the location of the target node is defined by the centroid of the formative polymath.

Range-based localization algorithm includes received signal strength indication(RSSI) ranging mechanism based on received signal strength, time of arrival(TOA) ranging mechanism based on time, and angle of arrival(AOA) measuring mechanism based on arrival direction [4-6]. RSSI ranging mechanism can utilize the attenuation model in which signal energy attenuation rate is inversely proportional to the square of distance, and calculate the distance in combination with the intensity of transmitted signal as well as the received signal. The application scope of this mechanism is relatively comprehensive for its low price, but its accuracy is lower when nodes density is low. TOA ranging technology, whose accuracy is higher than that of RSSI, can roughly estimate the distance between the transceivers by the arrival time of the signal. However, requirements for the hardware and high energy consumption restrict its further applications. AOA measuring mechanism serves as complementary mechanism of the two ranging schemes above, which provides azimuth or angle rather than distance messages to neighboring sensors. Implementation of this mechanism requires the support of multiple antennas, and hence, it demands high-performance hardware, also leading to limitation of large-scale applications.

2.2. Technical difficulties

The DV-Hop algorithm requires that the anchor nodes whose locations are known share a small proportion of the entire network and their communication capabilities are analogous to those of ordinary nodes. However, in practical applications, chances are that density of network nodes is relatively low along with uneven nodes distribution. Errors could be much larger under such circumstances.

ATIP cannot be applied to the following situations: randomly distributed nodes, irregular wireless signal models, low communication overhead requirements, etc. If ATIP's algorithm is robust, the prerequisite of dense nodes distribution must be met. If the nodes are paralyzed or the communication between nodes fails, it is highly likely that algorithm failure will occur. Meantime, the number of hops between nodes is not necessarily proportional to the actual distance, and is easily affected by obstacles and noises.

The main factors affecting RSSI include multipath fading effect and obstacle interference. When signals of different amplitude and phase frequency arrive at one receiver at the same time, it is inevitable that central frequency will be affected to a certain extent, leading to selective frequency attenuation. In addition, there are environmental obstacle factors. To be more specific, in the process of signal transmission, it is unavoidable to be affected by various kinds of environment blocks. Sometimes even diffraction happens, and the signal will certainly decay, which is called the shadow effect. Therefore, in combination with the all the factors above, the accuracy error of RSSI ranging could reach an extent of $\pm 50\%$. The requirement for energy consumption of TOA is comparatively high. And for the reason that wireless signal transmission speed is pretty fast, even relatively little difference of time measurement will eventually result in a great error of distance measurement. Hence, TOA applies to slow signal, such as underwater sensor positioning based on sonar. The AOA is also energy-consuming because its hardware foundation is ultrasonic receiver and antenna array installed on nodes, which means the cost could be great so as to achieve higher accuracy. What's more, the perception range of each node in wireless network is diverse according to specific application scenarios, for example, the sensing range of nodes with insufficient power will be narrowed. All of these uncertainties will affect the positioning accuracy of wireless sensors [6].

2.3. Developing trend

As one of the most basic technologies of WSN, location aware technology is becoming more and more mature in the fields of Internet of things, group positioning and information technology, exhibiting a very broad development prospect [7-9]. In the future, the development trend is listed as follows.

2.3.1. Positioning accuracy improvement

At present, although algorithms such as TOA, AOA are capable of providing relatively accurate positioning results. The deficiency of low-precision under certain circumstances due to their limitations is also obvious as explained above. Therefore, strengthening underlying theory research and optimizing algorithms as well as theoretical frame of node localization in order to further enhance the positioning accuracy of sensor nodes is one of the primary tendencies in the future.

2.3.2. Disposal of localization data

With the continuous progress of WSN, the amount of time data obtained by sensors is also mounting. So it is indispensable to ameliorate the processing forms of spatial-temporal data for sensors nodes in localization to avoid or reduce cumulative errors. Besides, strengthening data-storage capacity of the nodes' hardware and quality inspection and control during the process of data transmission are also essential.

2.3.3. Energy supply of location nodes

The energy consumption of sensor node localization mainly derives from two aspects, data processing and wireless transmission. Power consumed by the latter is much higher than that of the former. In the early stage of the development of WSN, the available energy of sensor power supply is very limited, so most of the load power of practical sensors is low, such as temperature and humidity sensors. Energy supply problems restricted the large-scale utilization of wireless sensor networks [8-9]. On the other hand, in order to extend service life of the sensors, heightening the availability of the energy supply for the positioning nodes is an inevitable developing trend of WSN in the future.

3. Data fusion of WSN

Wireless sensor network is composed of a plurality of sensor nodes with spatial distribution. Asynchronous clocks, observations asynchrony as well as information transmission delay is unavoidable. Consequently, considerable data from homogeneous or heterogeneous sensor nodes is processed when these sensors cooperate to complete the same task. Precisely speaking, specific algorithms are employed to analyze and fuse the data for the purpose of eliminating redundant data in the network, replenishing missing data by using redundant messages and reducing data traffic in the network. This kind of information integration analysis technology in wireless network is data fusion technology.

3.1. Fusion hierarchical partition

In the process of data fusion, three levels could be divided according to different abstract hierarchy division during data fusing: data layer fusion, feature layer fusion and decision level fusion [12-15].

3.1.1. Data layer fusion

For the data layer fusion, which belongs to the most fundamental stage of data fusion, information is acquired directly from sensors in the fusion process. More concretely, fusion of massive data from diverse sensors is administered firstly, and then primary features are extracted from fusion results.

One of the prerequisites of data layer fusion is that all of the data must originate from homogeneous sensors. In order to guarantee all the messages disposed derive from the same target, original data is interrelated firstly in the fusion procedure. In addition, the amount of lost information in the process of integration is minimal, and target's information acquired from this layer is the maximum compared with other fusion layers. In other words, the data layer fusion could ensure the

highest fusion accuracy.

However, obvious shortcomings also exist in data layer fusion.

1. Considerable data amount. The object is intact initial data, causing calculation time is relatively long, which means real-time information cannot be guaranteed.
2. Single fusion type. Sources of sensing data have to be the same type, leaving data from heterogeneous sensors to higher fusion levels.
3. High communication bandwidth: With substantial data to be handled, the system requires high communication bandwidth for transmission, resulting in a poor ability of interference resisting.
4. Poor fault-tolerance ability. The performance of single sensor generates a direct effect on overall fusion situation.

3.1.2. *Feature layer fusion*

Trademarks of the measured target will be accessible after the fusion of raw data, namely object abstraction characteristics or behaviors, usually in the form of statistics or indicator of initial data, which can express azimuth, region or other information. The feature layer fusion integrates these trademarks into single feature vector, that is, joint feature information vector, by using certain rules, and utilizes pattern recognition method to further process the data in preparation for the next fusion level.

The feature layer fusion is essentially separated into two categories: state fusion and information fusion. The typical case of the former is solving the multi-target tracking problem, and the latter is related to pattern discernment [13]. For the reason that the amount of initial data will be substantially compressed after data layer fusion, one palpable advantage over the previous level lies in less fusion data processed. On the one hand, it decreases background computing time and improves real-time performance of information. On the other hand, it enhances anti-interference ability because of low requirements for bandwidth. Another notable merit is that processed data does not have to be derived from homogeneous sensors, broadening the scope of its application and strengthening the multidimensional representation ability. Nevertheless, disadvantages of feature layer fusion are also significant due to data integration. Certain data is inevitably abandoned or lost in the data fusion process, leading to degradation of fusion accuracy.

3.1.3. *Decision layer fusion*

Decision layer fusion belongs to highest integration level. Single independent attribute decisions are made for characteristics from feature layer fusion, and then decision data from various sensors is fused, ensuring the final decision level fusion results are consistent as a whole [15].

Analogous to those of feature level fusion, the advantages of decision level fusion are lower bandwidth, stronger anti-interference ability and that the performance of single sensor could hardly generate an influence on the fusion. What's more, the data can also be derived from heterogeneous sensors. Similarly, maximum amount data is lost due to convergence of decision fusion layer and, thus, the accuracy of this level is the lowest in these three levels.

3.2. *Introduction of fusion algorithms*

The basic of fusion process is fusion algorithms, and the specific requirements for its operation are that multivariate data is processed on different fusion levels as the input according to actual demands. The judgment is implemented in the light of concrete fusion features. Currently, embedded algorithm, evidence combination and artificial neural network are three relatively popular algorithms.

3.2.1. *Embedded algorithms*

In the process of analyzing the target, the first step is to obtain theoretical values on the basis of the mapping theory hypothesis, and then the sensed data is mapped as objective environment. Finally, the pre-image is solved based on data fusion technology [14]. The most commonly used theory of embedded algorithm is Bayesian theory.

Bias theory has the aid of the Gauss distribution function (classical conditional probability density distribution function) parameter expression and prior probability, and utilizes Bias formula to transform the prior probability into posterior probability, and by the magnitude of which classification of decision-making is implemented. The advantage of Bias theory is that the state of unknown section can be expressed by subjective probability under the circumstance of incomplete information and, afterwards, the most reasonable determination can be reached by utilizing the possibility modified by Bias formula. For a long time, Bias theory has been regarded as the fundamental approach to the solution of multivariate data fusion problem. Nevertheless, with the application of practical issues continue to deepen, Bayesian theory gradually exposed mounting weaknesses. For example, it failed to distinguish the two concepts of uncertainty and distrust effectively and there is no direct way to express the two concepts of uncertainty and unknown in Bayesian theory [16].

3.2.2. *Evidence combination method*

The evidence combination method is based on partial information of the target. Firstly, several possible fusion results could be obtained as undetermined decisions by employing data fusion to carry on decision-making task. Then the mastered information is properly handled and expressed, through which the most rational decisions could be ascertained within those undetermined ones. Specifically, the first step is analyzing every piece of data from sensors to allow it to exhibit supporting degree for every undetermined decision. Then the degree of support from different sensors for each pending decision will be fused, and ultimately, the one owing the most support will be identified as the final decision.

Exact sensor model is not required, which is the most notable advantage of evidence combination method, compared with embedded algorithm. Another is that available sensor information could be employed as prior condition. The trust degree of each hypothesis can be established by computer, leading to the best decision ultimately.

The most common evidence combination theory in practical application is D-S evidence theory. According to this theory, a set of possible events rather than probability value is adopted to represent uncertainty, and trust function is introduced to distinguish the two concepts of uncertainty and distrust. The primary difference between D-S theory and the others is that one proposition will have two different uncertainty measures in this theory. The evidence could be used to judge whether a proposition is founded or not, while it cannot fully support or negate this proposition for the existence of uncertainty. D-S theory has great flexibility and, hence, its application scope is extensive, especially for data fusion in multi-source wireless network.

3.2.3. *Artificial neural network method*

Artificial neural network is a bionic method that simulates fusion pattern of information processing of human brain. Before merging, the standard of classification will be determined by the neural network according to similarities between messages. In fact, the inference process is usually combined with depth learning to obtain the uncertainty reasoning mechanism.

The first step of multi-source sensor data fusion is to determine the classification criterion in light of hallmarks of diverse sensors and requirements after fusion. The input information is then represented in certain way as a total input function and is regarded as a fixed mapping function in subsequent process. Finally, the learning algorithm of neural networks is used to learn the output data of sensors along with weights assigning.

3.3. *Developing trend of fusion algorithms*

Fusion algorithm has a wide range of application at present, including artificial intelligence, statistical census, monitoring and remote sensing [17-20]. In the foreseeable future, the application of the sensor fusion algorithm will become more mature and diversified, and the development trend of the fusion algorithm is mainly as follows:

1. Further strengthen the study of the underlying theory of multi-source data fusion in WSN,

optimize the elementary theoretical framework and method of data fusion, establish and perfect the basic theory and method of multi-sensor integration and data fusion.

2. Integrate AI technology, such as depth learning, intelligent control, pattern recognition and voice recognition, as much as possible in the field of data fusion to provide technical support for more and more extensive application spheres.

3. Enhance self-learning function of the diagnosis system. One way to realize this is to add self-learning module, through which fault information could be delivered to the back-end database and the corresponding trust factor will be updated in time. Meantime, according to the information in the database, the self-learning module can carry out dynamic reasoning, for example, behavior and intention interference based on spatial-temporal messages, and constantly update the database to realize self-learning function.

4. So far the data fusion has been, to a large extent, a relatively simple synthesis of information, which, in a sense, caused tremendous waste of data. Hence, it is absolutely essential to heighten the utilization of redundant information offered by sensors to achieve the high-intelligence processing, which is prospected to be a future developing trend of WSN data fusion.

5. Ameliorate the supporting environment of data fusion by improving the hardware, such as data interface and transmission lines, to elevate swift user-oriented ability of data fusion system.

4. Conclusion

Two primary technologies of WSN, location awareness and data fusion, are elaborated. Basic contents, main methods and their merits as well as shortcomings, and expectations of future development trends are reviewed.

WSN still owns a promising future with broad developing prospects, more intelligent and more integrated. Moreover, if the algorithms of these two technologies can be optimized and hardware support device can be improved, the application of WSN will indubitably be more extensive in the future.

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